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NASA CR-144006

Prepared for the
GEORGE C. MARSHALL
SPACE FLIGHT CENTER
Huntsville, Alabama

30 April 1975

Contract No. NAS8-31309
Exhibit A Section A
IBM No. 75W-00061

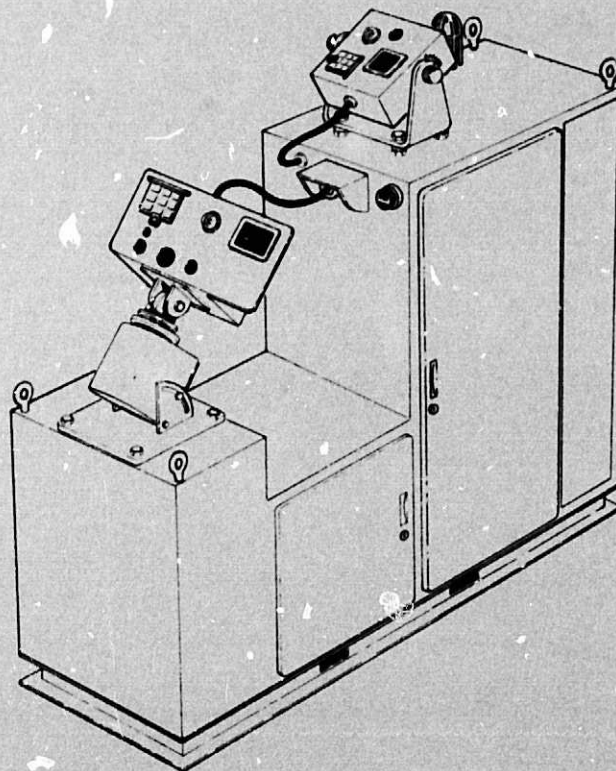
SUNFALL MONITOR CALIBRATION PLAN

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(NASA-CR-144006) SUNFALL MONITOR
CALIBRATION PLAN (International Business
Machines Corp.) 19 p HC \$3.25 CSCL 14B



IBM

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Prepared By

R. B. Lollar

Program Office Approval

[Signature]



Federal Systems Division, Space Systems/Huntsville, Alabama

TABLE OF CONTENTS

Section	Title	Page
1	Introduction-----	1
2	Pyrheliometer Calibration-----	1
2.1	Initial On-Site Calibration-----	1
2.2	Periodic Calibration-----	1
3	Pyranometer Calibration-----	3
3.1	Initial On-Site Calibration-----	3
3.2	Periodic Calibration-----	3
4	Equatorial Mount Calibration-----	7
4.1	Leveling-----	7
4.2	Latitude Setting-----	7
4.3	Hour Angle Adjustment-----	7
4.4	Declination Adjustment-----	9
4.5	General-----	9
5	Data Management System Calibration-----	9
5.1	D2020 Calibration-----	9
5.2	Kennedy 1610 Tape Recorder Calibration-----	14

LIST OF FIGURES

Figure		Page
1	Declination Angle of the Sun-----	10
2	D2020 With Bottom Cover and Side Plates Removed-----	11
3	D2020 Rear Panel View-----	13

LIST OF TABLES

Table		Page(s)
1	Pyrheliometer Calibration Procedure-----	2
2	Pyranometer Calibration Procedure-----	4,5,6
3	True Solar Time Corrections to Central Standard Time at 86.64 Degrees Longitude-----	8

1.0 INTRODUCTION

The calibration performed on the Sunfall Monitor will consist of an initial on-site calibration of the unit when first installed at the Marshall Space Flight Center (MSFC) and, thereafter, periodic calibration and adjustments as required for the different components of the monitor. Initial on-site calibration will be performed by IBM and the Eppley Laboratory. Periodic calibration and adjustment will be the responsibility of the Marshall Space Flight Center. The requirements for calibration and adjustment are described in the following sections.

2.0 PYRHELIOMETER CALIBRATION

2.1 Initial On-Site Calibration

Calibration of the Sunfall Monitor pyrheliometers performed by the Eppley Laboratory on-site at the Marshall Space Flight Center will essentially be a verification of the individual sensitivity factors assigned to each instrument at the time of their calibration at the Eppley Laboratory. Calibration of these two Eppley Normal Incidence Pyrheliometers (NIPs) located in the tracking canister of the Sunfall Monitor will be accomplished by direct comparison against the output of an Angstrom pyrheliometer furnished from the Eppley group of reference standards that maintain the International Pyrheliometric Scale. Adequate solar tracking will be required during the period of calibration. The step-by-step calibration procedure is to be performed by the Eppley Laboratory upon initial setup and then once every two years, thereafter, as described in Table 1.

Within thirty (30) days prior to the on-site calibration of the NIPs, the Angstrom pyrheliometer to be used on-site will be intercompared with other standard Angstroms maintained at Eppley to verify its calibration. After the on-site calibration of the NIPs has been performed, this same Angstrom will again be intercompared for purposes of verifying its accuracy. The digital volt meter used as a readout device, in conjunction with the Angstrom, will also be calibrated before and after the on-site calibration, against the Eppley group of reference Standard Cells which have been certified by the National Bureau of Standards.

2.2 Periodic Calibration

Periodic calibration of the Sunfall Monitor pyrheliometers should be performed every three months by trained personnel utilizing the procedure listed in Table 1. During these calibration periods, an on-the-shelf Angstrom pyrheliometer should be utilized for calibrating the two pyrheliometers. This on-the-shelf Angstrom pyrheliometer should be returned to Eppley once a year for a calibration check.

With initial on-site calibration occurring in July, periodic calibration should occur in January, April, July and October of each year with Eppley Laboratory on-site calibration being performed each odd number year (i.e., 1977, 1978, etc.) during the month of July.

TABLE 1
PYRHELIOMETER CALIBRATION PROCEDURE*

1. Make sure N.I.P. is tracking properly, the sight lined up, and the millivolt output is recording correctly.
2. Place Angstrom in sun with cap on, plug into control box. Turn on control box with function switch in off position.
3. Wait one-half hour for warm up.
4. Zero galvanometer by depressing ZERO switch and simultaneously null detector with ZERO potentiometer on null detector.
5. Line up Angstrom on sun, remove cap, set switch on Angstrom in middle position (M).
6. Switch function switch to A1 and zero galvanometer with zero knob.
7. Switch on Angstrom to right (R). Null galvanometer by using coarse and fine adjusting knobs. Switch to left (L) and null galvanometer. (This step is to bring coarse and fine adjustment to approximately the proper position, so that when the actual calibration begins too much time will not be wasted adjusting the coarse and fine knobs.)
8. Note date, location, temperature and Angstrom number.
9. Line Angstrom on sun and switch to right (R). Null galvanometer. The galvanometer has to stay on null for 5 seconds. When this is achieved, read D.V.M. which is reading milliamps, record time and D.V.M. reading. There are three conditions to take a reading: (a) the Angstrom has to be on the sun; (b) the needle on the galvanometer steady; (c) and at null for at least 5 seconds.
10. Switch to left (L) and repeat step 9. Record D.V.M. reading.
11. Repeat right and left till three rights and three lefts have been achieved, record time at the last left reading. (With a little practice about 4 minutes should be the time to complete a set of readings.)
12. Take the average of the six readings and use the formula $I = ki^2$ to calculate the Intensity (I). Note i (current) is in amps. The k factor will already be assigned to the Angstrom.
13. To calibrate the N.I.P. millivolt output, over the same period of time, divide the millivolt output by the Intensity (I) in $\text{cal/cm}^{-2} \text{ min}^{-1}$ to obtain the sensitivity of the N.I.P.
14. Repeat this procedure 4 or 5 times to ensure accuracy of readings.

*Calibration should be performed when the sky is clear and free of clouds.

3.0 PYRANOMETER CALIBRATION

3.1 Initial On-Site Calibration

Initial on-site calibration of both pyranometers utilized in the Sunfall Monitor will be performed to verify the individual sensitivity factors assigned to each instrument at the time of their calibration at the Eppley Laboratory. The calibration of these pyranometers will be performed using one of the North American Mean standard pyranometers supplied by Eppley Laboratory. This standard pyranometer will be mounted to a flat plate which will be attached to the non-tracking assembly of the Sunfall Monitor. In this configuration, the orientation angle of both the standard pyranometer and the pyranometer located on the non-tracking assembly will be the same. The pyranometer located on the tracker assembly will be oriented to the same angle with respect to the horizontal as the standard pyranometer. The step-by-step calibration procedure to be performed by the Eppley Laboratory, upon initial set up and then once every two years thereafter, is described in Table 2.

Within thirty (30) days prior to the on-site calibration of the two pyranometers, the standard pyranometer to be used in the calibration will be inter-compared with the standard Angstrom pyrhemometers using the shading method. After the on-site calibration of the pyranometers has been performed, the standard pyranometer will again be intercompared for purposes of verifying its accuracy. The digital voltmeter used as a readout device, in conjunction with the North American Mean standard pyranometer, will also be calibrated, before and after the on-site calibration, against the Eppley group of reference Standard Cells which have been certified by the National Bureau of Standards.

3.2 Periodic Calibration

Periodic calibration of the pyranometers used in the Sunfall Monitor should be performed every three months by trained personnel utilizing the calibration procedure presented in Table 2. An on-the-shelf Eppley Precision Spectral Pyranometer should be utilized to perform this calibration. This on-the-shelf pyranometer should be kept in its case and located indoors at all times except when it is to be used during the calibration periods. This on-the-shelf pyranometer should be returned once a year to Eppley for a calibration check.

With initial on-site calibration occurring in July, periodic calibration should occur in January, April, July and October of each year with Eppley laboratory on-site calibration being performed each odd number year (i.e., 1977, 1979, etc.) during the month of July.

Table 2
(Sheet 1 of 3)
Pyranometer Calibration Procedure*

1. Attach standard pyranometer to calibration mounting bracket.
2. Attach calibration mounting bracket to non-tracking tiltable surface.
3. Calibrate digital voltmeter against the output of a precision millivolt test source.
4. Connect digital voltmeter to standard pyranometer output wires.
5. Place non-tracking tiltable surface into horizontal position. (This places standard pyranometer and non-tracking pyranometer into horizontal plane.)
6. Remove electrical power from equatorial mount to stop tracking motion by switching off circuit breaker.
7. Manually place tracking pyranometer into horizontal position by adjusting equatorial mount into the proper orientation.
8. Take simultaneous millivolt readings from the standard pyranometer, non-tracking pyranometer, and the tracking pyranometer. (Millivolt readings for non-tracking and tracking pyranometers will be printed out by the D-2020 printer.)
9. Place millivolt readings taken in step 8 into equations (A) and (B) along with the known sensitivity (SPsen) of the standard and solve for the sensitivity (NTPsen and TPsen) of the non-tracking and tracking pyranometers.

*Calibration should be performed on day when the sky is clear and free of clouds.

Table 2
(Sheet 2 of 3)
Pyranometer Calibration Procedure

$$\frac{NTPmv}{NTPsen} = \frac{SPmv}{SPsen}$$

$$(A) \ NTPsen = \frac{(NTPmv) \times (SPsen)}{SPmv}$$

where: NTPsen = non-tracking pyranometer sensitivity
NTPmv = non-tracking pyranometer millivolt reading
SPmv = standard pyranometer millivolt reading
SPsen = standard pyranometer sensitivity

$$\frac{TPmv}{TPsen} = \frac{SPmv}{SPsen}$$

$$(B) \ TPsen = \frac{(TPmv) \times (SPsen)}{SPmv}$$

where: TPsen = tracking pyranometer sensitivity
TPmv = tracking pyranometer millivolt reading
SPmv = standard pyranometer millivolt reading
SPsen = standard pyranometer sensitivity

10. Repeat steps 8 and 9 three times, then take the average of the three calculated values for NTPsen to obtain an average value for NTPsen, and also average the three calculated values for TPsen to obtain the most accurate value of TPsen.

Table 2
(Sheet 3 of 3)
Pyranometer Calibration Procedure

11. Tilt all pyranometers including the tracking pyranometer, to the angle which the non-tracking surface will be maintained during routine operation.
12. Repeat steps 8, 9 and 10. The values calculated for NTPsen and TPsen in the non-horizontal position should be the same as those calculated in the horizontal.
13. Values for NTPsen should be within $\pm 2\%$ of nameplate sensitivity

$$8.81 \times 10^{-6} \text{ volts/watt meter}^{2*}$$

or

$$6.14 \text{ millivolts/cal cm}^2 \text{ min}^*$$

If NTPsen is not within $\pm 2\%$ of the nameplate sensitivity, then the non-tracking pyranometer should be sent to Eppley Laboratory for calibration and a new nameplate.

14. Values for TPsen should be within $\pm 2\%$ of nameplate sensitivity

$$8.69 \times 10^{-6} \text{ volts/watt meter}^{2*}$$

or

$$6.06 \text{ millivolts/cal cm}^2 \text{ min}^*$$

If TPsen is not within $\pm 2\%$ of the nameplate sensitivity, then the tracking pyranometer should be sent to Eppley Laboratory for calibration and a new nameplate.

15. Note date, location, temperature and serial number of the standard pyranometer used in the calibration.

*Note: These values will change when the pyranometer is recalibrated at the Eppley Laboratory.

4.0 EQUATORIAL MOUNT CALIBRATION

4.1 Leveling

The equatorial mount will initially be leveled, utilizing a precision level to within \pm thirty minutes of arc from true horizontal, and should not vary provided the leveling screws are not tampered with or sinking of the pad on which the Sunfall Monitor is mounted does not occur. A level located on the base of the equatorial mount should be utilized to verify leveling of the base in the north-south and east-west directions. This level check should be performed each time hour angle and declination adjustments are made to the equatorial mount.

4.2 Latitude Setting

The equatorial mount will be tilted up from horizontal to the latitude of the site, as indicated on the 0° to 90° scale engraved on the quadrant plate. At this angular position the equatorial mount will be securely clamped between the two quadrant plates by tightening up (with a wrench) both bolts provided for this purpose. The latitude setting should remain unchanged as observed by visual inspection. Therefore, a visual inspection should be made on each visit to the Sunfall Monitor to verify correctness of this setting.

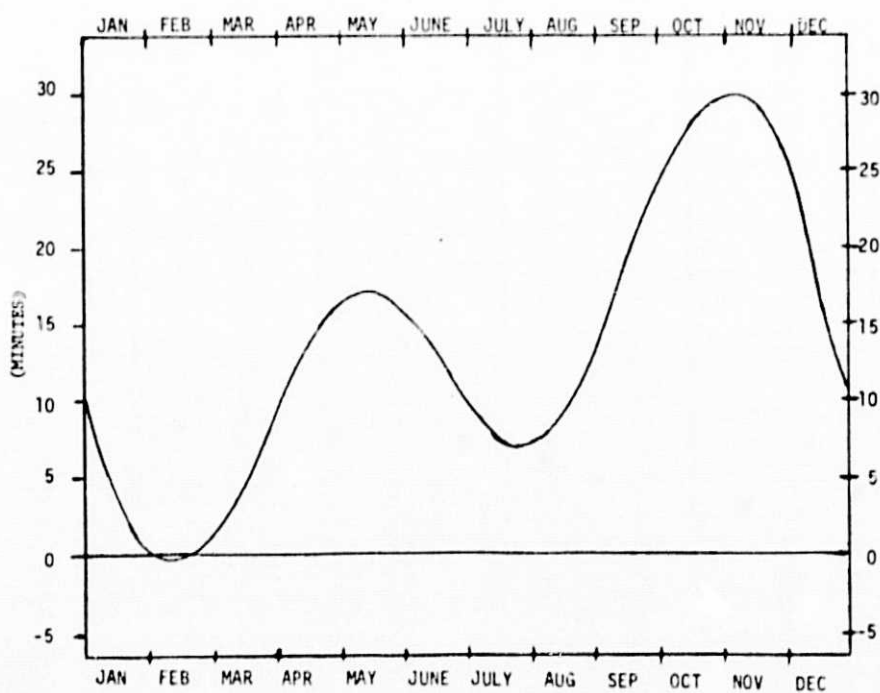
4.3 Hour-Angle Adjustment

The reference point for sighting the sun is the black dot located on the white circular target on the rear bracket of the pyrhelionometer. Adjustments to the hour angle axis, which is measured east to west in the direction of daily tracking, can be made by turning the hour angle screw in the proper direction with the objective of keeping the bright spot, produced by the sun shining through the pinhole of the bracket at the top of the pyrhelionometer, centered on this black dot as observed visually. If the bright spot gets outside of the white circular target, the pyrhelionometer output will not be accurate. Table 3 shows the adjustments to be made in hour angle during the year. The time scale on the equatorial mount will be set to read True Solar Time (TST) for the longitude at which the Sunfall Monitor is located. The yearly adjustments made with the hour angle screw will keep the equatorial mount tracking on TST.

The clutch mechanism of the equatorial mount will initially be adjusted so that the assembly of sensors atop the mount can be manually rotated without the clutch being too stiff or too free. The best clutch pressure is that which permits an easy but firm adjustment of the hour angle position without undue strain being imposed upon the clutch mechanism and also is capable of withstanding the effects of the wind. If the motion against the clutch friction is too stiff or too free, then the waterproof cover must be removed and the clutch tension spring adjusted by screwing either in or out the pair of nuts (one serving to lock the other) at the end of the driving shaft. Should the clutch spring be so tight that the drive is rigid, attempts to adjust the hour angle setting may loosen set screws securing the turntable to the shaft, in which case they will require tightening again.

Table 3. True Solar Time Corrections (In Minutes) to Central Standard Time
At 86.64 Degrees Longitude

MONTH DATE	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	D.C.	MONTH DATE
01	10.4	-0.1	0.9	9.3	16.3	15.8	9.8	7.1	13.3	23.6	29.7	24.7	01
02	9.9	-0.2	1.1	9.6	16.4	15.6	9.6	7.2	13.6	23.9	29.8	24.4	02
03	9.5	-0.3	1.3	10.0	16.6	15.4	9.4	7.2	13.9	24.2	29.8	24.0	03
04	9.0	-0.5	1.5	10.3	16.6	15.3	9.2	7.3	14.3	24.5	29.8	23.6	04
05	8.5	-0.6	1.7	10.6	16.7	15.1	9.0	7.4	14.6	24.8	29.8	23.2	05
06	8.1	-0.7	2.0	10.8	16.8	14.9	8.9	7.5	14.9	25.1	29.7	22.7	06
07	7.6	-0.8	2.2	11.1	16.9	14.7	8.7	7.6	15.3	25.4	29.7	22.3	07
08	7.2	-0.8	2.5	11.4	16.9	14.6	8.5	7.7	15.6	25.7	29.7	21.9	08
09	6.8	-0.9	2.7	11.7	17.0	14.4	8.4	7.8	16.0	26.0	29.6	21.4	09
10	6.4	-0.9	2.9	12.0	17.0	14.2	8.2	7.9	16.3	26.3	29.5	21.0	10
11	5.9	-0.9	3.2	12.2	17.1	14.0	8.1	8.1	16.6	26.5	29.4	20.5	11
12	5.5	-0.9	3.5	12.5	17.1	13.8	8.0	8.2	17.0	26.8	29.3	20.1	12
13	5.1	-0.9	3.7	12.8	17.1	13.6	7.8	8.4	17.3	27.0	29.2	19.6	13
14	4.7	-0.9	4.0	13.0	17.1	13.4	7.7	8.6	17.7	27.3	29.1	19.1	14
15	4.4	-0.9	4.3	13.2	17.1	13.2	7.6	8.7	18.1	27.5	28.9	18.6	15
16	4.0	-0.8	4.6	13.5	17.1	12.9	7.5	8.9	18.4	27.7	28.7	18.2	16
17	3.6	-0.3	4.9	13.7	17.1	12.7	7.4	9.1	18.8	27.9	28.5	17.7	17
18	3.3	-0.7	5.2	13.9	17.1	12.5	7.3	9.5	19.1	28.1	28.3	17.2	18
19	3.0	-0.6	5.4	14.2	17.1	12.3	7.3	9.8	19.5	28.3	28.1	16.7	19
20	2.7	-0.6	5.7	14.6	17.0	12.1	7.2	10.0	19.8	28.5	27.9	16.2	20
21	2.4	-0.5	6.0	14.6	17.0	12.1	7.1	10.2	20.2	28.7	27.7	15.7	21
22	2.1	-0.4	6.3	14.8	16.9	11.9	7.1	10.5	20.5	28.8	27.4	15.2	22
23	1.8	0.2	6.6	15.0	16.9	11.7	7.1	10.7	20.9	29.0	27.1	14.7	23
24	1.5	0.1	6.9	15.2	16.8	11.4	7.0	11.0	21.2	29.1	26.9	14.2	24
25	1.2	0.3	7.2	15.4	16.6	11.2	7.0	11.3	21.6	29.2	26.6	13.7	25
26	1.1	0.2	7.6	15.6	16.5	11.0	7.0	11.5	21.9	29.3	26.3	13.2	26
27	0.8	0.4	7.8	15.7	16.4	10.8	7.0	11.8	22.3	29.4	25.9	12.8	27
28	0.6	0.5	8.2	15.9	16.3	10.6	7.0	12.1	22.6	29.5	25.6	12.3	28
29	0.4	0.7	8.5	16.0	16.2	10.4	7.0	12.4	22.9	29.6	25.3	11.8	29
30	0.2		8.8	16.2	16.0	10.2	7.1	12.7	23.3	29.7	24.9	11.3	30
31	0.1		9.1		15.9		7.1	13.0		29.7		10.8	31



4.4 Declination Adjustment

As in the case with the hour angle adjustment, the objective of declination adjustment is to keep the bright spot, produced by the sun shining through the pinhole of the bracket at the top of the pyr heliometer, centered on the black dot located on the white circular target on the rear bracket of the pyr heliometer. If the bright spot gets outside the white circular target, the pyr heliometer reading will not be accurate.

Adjustments to the yearly variation in solar declination, which is measured on a longitudinal plane in a north and south direction, can be made through movement of the declination screw after loosening the clamping screw which should be tightened when the desired adjustment is effected. Where the most accurate tracking is required, this adjustment should be inspected each day, although there are times of the year when no change in this adjustment setting will be necessary for several days at a time. Figure 1 shows the sun's declination throughout the year. The appropriate declination scale, 25-0-25 degrees, is provided.

4.5 General

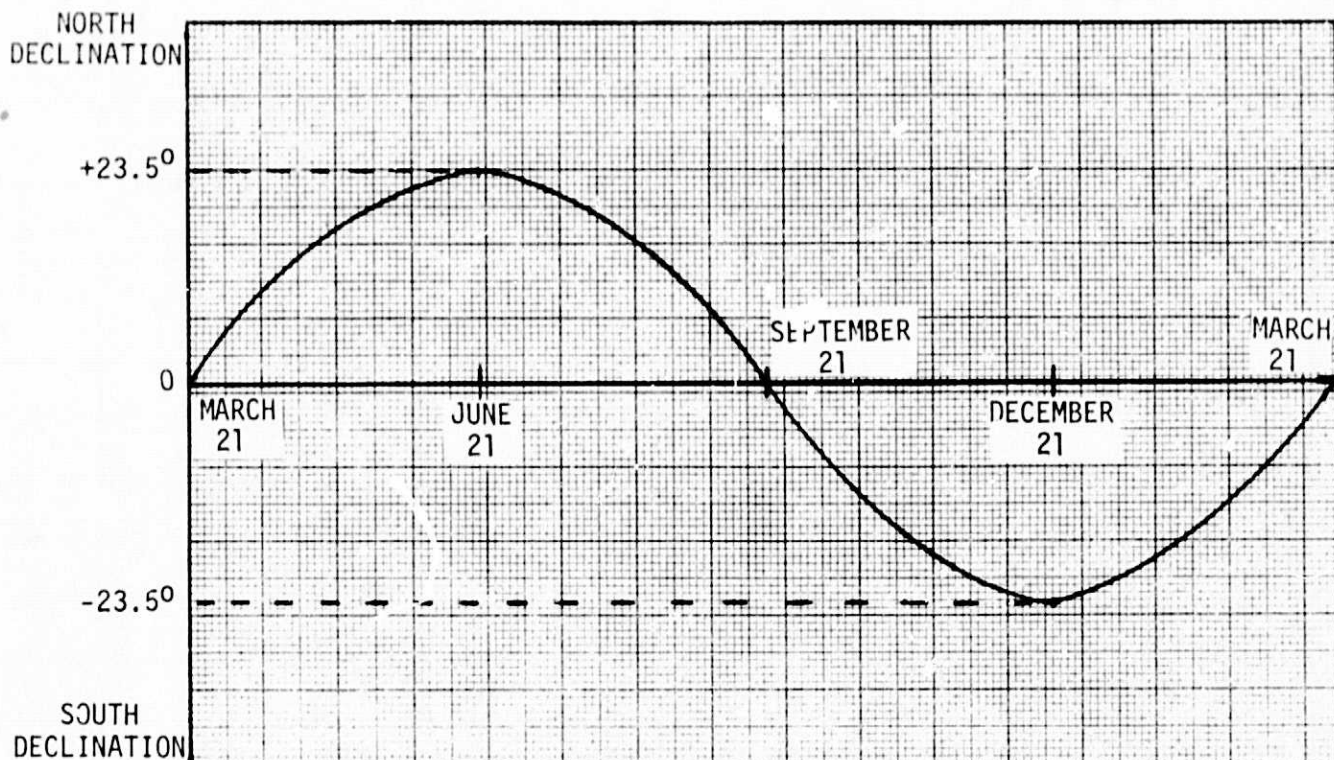
If, after the operations described above have been undertaken, the solar tracking is not as precise as wished (as evidenced by the light spot position on the painted circular target), then the reason is probably either a faulty North-South setting or a faulty latitude setting, as the leveling of the base stand is straight forward and the declination adjustment is precisely machined. Further trial and error attempts should then be made, after setting the declination value from consultation of Figure 1 and also the hour angle position Table 3. The North-South alignment and the latitude setting should be altered in turn, but only slightly at any one time, until the best positions are found. If the most accurate possible solar tracking is desired, the objective should be to prevent the light spot from drifting away from the center of the target by a distance not greater than the spot diameter. However, for practical purposes, this drift may reach two diameters before the pyr heliometer thermopile sensor begins to lose sight of the total solar disc, thus creating a non-valid pyr heliometer reading.

5.0 DATA MANAGEMENT SYSTEM CALIBRATION

5.1 Esterline Angus D2020 Calibration

Zero and span controls, as shown in Figure 2, are provided on the input amplifier converter PC card for the calibration of the input measurement ranges. These adjustments are precisely set at the factory and should not require readjustment in the field.

However, if a new input amplifier/converter PC card has been installed or if associated components on the card have been replaced, recalibrate the A-D measuring circuits as follows:



DATE DEGREES

Jan. 1 -23.08
6 -22.60
11 -21.94
16 -21.10
21 -20.09
26 -18.93
31 -17.62

Feb. 1 -17.34
6 -15.88
11 -14.30
16 -12.63
21 -10.87
26 -9.04

Mar. 1 -7.91
6 -6.00
11 -4.05
16 -2.09
21 -0.11
26 +1.86
31 +3.82

DATE DEGREES

Apr. 1 +4.20
6 +6.12
11 +7.99
16 +9.81
21 +11.56
26 +13.23

May 1 +14.81
6 +16.29
11 +17.65
16 +18.89
21 +20.00
26 +20.97
31 +21.79

June 1 +21.93
6 +22.56
11 +23.02
16 +23.32
21 +23.44
26 +23.39

DATE DEGREES

July 1 +23.17
6 +22.78
11 +22.23
16 +21.52
21 +20.65
26 +19.64
31 +18.49

Aug. 1 +18.25
6 +16.95
11 +15.54
16 +14.03
21 +12.42
26 +10.73
31 +8.97

Sept. 1 +8.61
6 +6.78
11 +4.90
16 +2.99
21 +1.05
26 -0.89

DATE DEGREES

Oct. 1 -2.84
6 -4.78
11 -6.69
16 -8.56
21 -10.38
26 -12.14
31 -13.82

Nov. 1 -14.15
6 -15.72
11 -17.18
16 -18.52
21 -19.72
26 -20.78

Dec. 1 -21.67
6 -22.39
11 -22.93
16 -23.28
21 -23.44
26 -23.40
31 -23.16

Figure 1. Declination Angle of the Sun

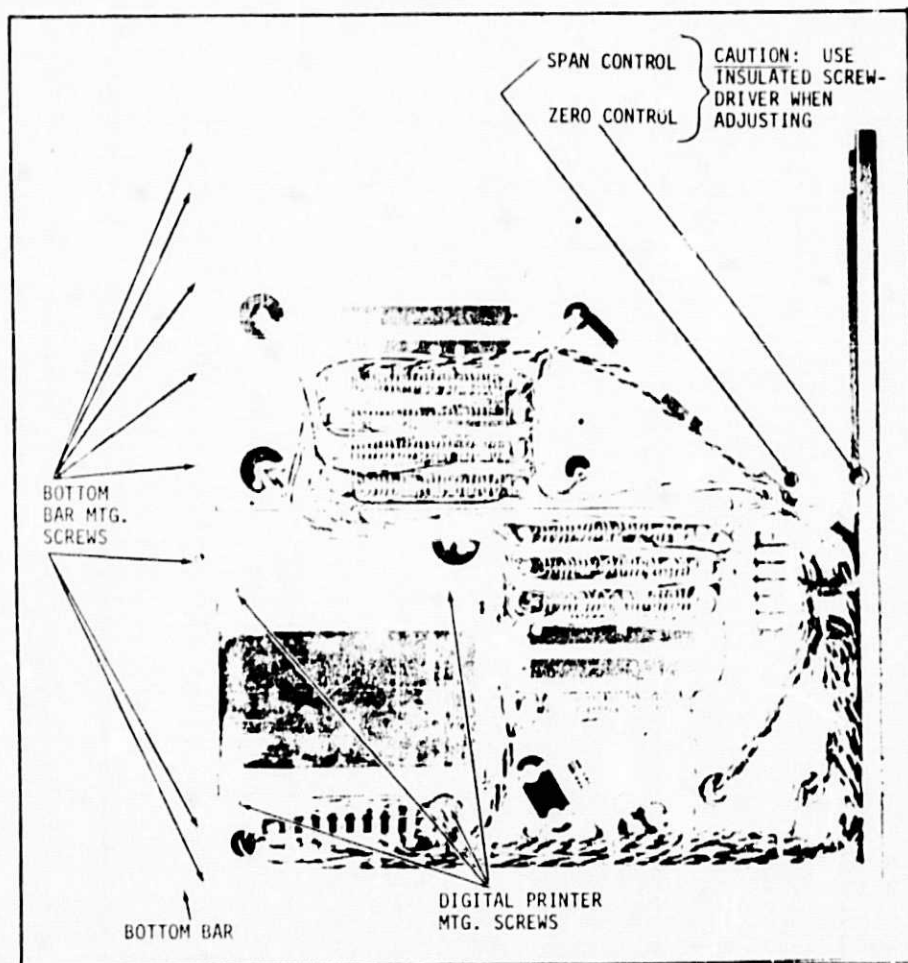


Figure 2. D2020 with Bottom Cover and Side Plates Removed

Equipment Required

Variable DC Voltage Standard (accuracy .005%); Esterline Angus Model V-2000, or equivalent.

Procedures

1. Remove bottom cover of instrument by removing the bottom cover retaining screws as shown in Figure 3.
2. Select appropriate channel input terminals on one of the relay mux/drivers PC cards at rear panel, and remove any external signal input leads which may be connected to these terminals. Short the terminals of the selected channel input.

NOTE: For identification of channel terminal numbering system refer to Figure 3.
3. Set controls on front panel to correspond to channel input selected on the rear panel as follows: Depress proper channel-select push-button and set proper gain switch to 100MV range.
4. Turn front panel FRAME RATE switch to EXT. TRIG. or AUX. position in order to inhibit the printer. Set the display mode switch in MEASURE position. Turn instrument power on. Use an insulated screwdriver and adjust zero control so that nixie display reads 000.0MV + .1MV, + one LSD (least significant digit) -- i.e., within -000.2MV to +000.2MV.
5. Remove short from terminals of selected channel input at rear panel.
6. Set output of voltage standard to 100MV, observe polarities, and connect reference output to selected channel input terminals at rear panel.
7. Use an insulated screwdriver and adjust span control so that nixie display reads 100.0MV + .1MV, + one LSD (least significant digit) -- i.e., within 99.8MV to 100.2MV.
8. Remove the voltage standard source, and reconnect any external signal input leads which were removed in Step 2 above. Replace bottom cover and resume normal operation.

NOTE: Calibration of the instrument on the 0-100MV range provides specified accuracy requirements on the other ranges also. However, if it is desired to optimize the accuracy of a particular range, apply appropriate calibration signals from the voltage standard and make adjustments as indicated in the following calibration table.

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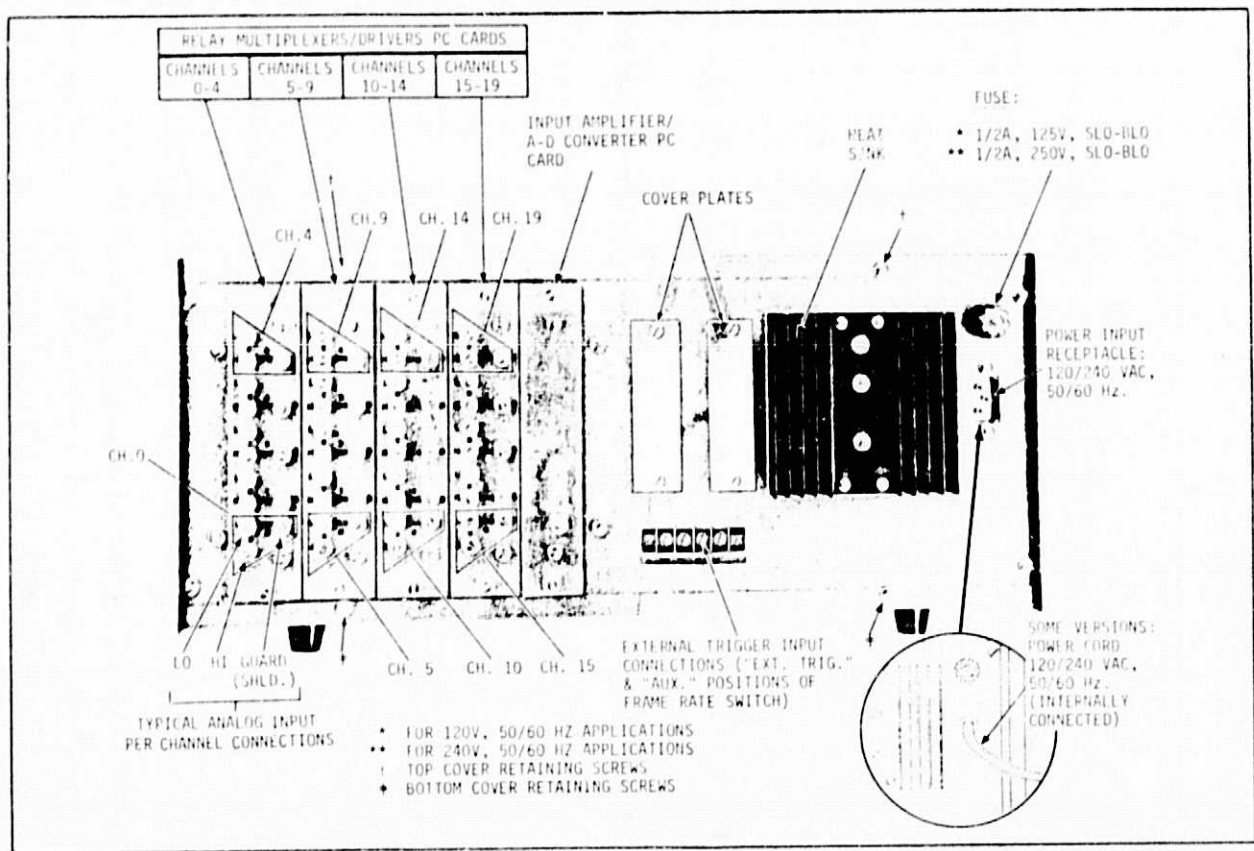


Figure 3. D2020 Rear Panel View

CALIBRATION ADJUSTMENTS

RANGE SELECTED	NIXIE DISPLAY READOUT	
	(Input Shorted) Adjust Zero Within:	(Full-Span Signal Applied) Adjust Span Within:
0-1MV	-0.006MV to +0.006MV	0.994MV to 1.006MV
0-10MV	-00.02MV to +00.02MV	9.980MV to 10.02MV
0-100MV	-000.2MV to +000.2MV	99.80MV to 100.2MV

5.2 Kennedy 1610 Tape Recorder Calibration

No calibration is required on the Kennedy 1610 Tape Recorder, but every time a magnetic tape is changed out on the tape recorder, a cotton ear swab dipped in rubbing alcohol should be wiped over the tape head assembly for purposes of cleaning the head.